Diagnostics and Modeling of Gas Puff Target Laser Plasma Radiation Source

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Here we present a study of XUV emission characteristics of nitrogen plasma induced by infrared laser pulse (800mJ/7ns) focused into a gas puff target. Spatial distribution of nitrogen density was determined by EUV radiography at the wavelength 13.5 nm. We used Gaussian function to approximate the cross-section of the gas puff target in the direction perpendicular to the axis of the nozzle. The value of target mass density was estimated to be $3.7{\cdot}10^{-4}$ g/cm^3 at the distance Δz = 0.5mm from the nozzle and $4.9{\cdot}10^{-4}$ g/cm^3 at Δz = 0.25mm from the nozzle. The resulting density profile at the focal region and measured time dependences of laser power were introduced as input data to 2D RMHD (Radiation- Magneto-Hydro- Dynamic) code Z* (EPPRA s.a.s, France). Spatial developments of nitrogen plasma quantities were modeled. The evaluated electron temperature at the center of gas puff target exceeded the value Te ~ 34 eV. The related peak value of emitted energy density, in the wavelength region 2.8766 – 2.8867 nm approached the value Qeuv ~ 0.3 J/cm^3. The evaluated spatial distributions of emitted energy were compared with the experimental data obtained with a compact laser-based XUV source (Laser-Laboratory Göttingen e.V., Germany).

Measurement of gas target density

We studied spatial mass density distributions of various gas puff targets in the XUV radiation source. The targets are formed by pulsed injection of a gas into vacuum through an electromagnetic valve synchronized with an irradiating laser pulse. The distance of targeting spots from the nozzle is 0.5 mm. We studied nitrogen, argon and krypton as working gas.

The experimental setup is shown in Fig. 2. The gas target was exposed by XUV generated using a laser-plasma XUV source. The gas target was located at the distance of 640 nm from the X-ray source.

The XUV radiation at the wavelength of about 13.5 nm was selected using a set of XUV filters composed of 20 μm thick Si and 10 μm thick Be foils and reflective Si/Mo mirror.

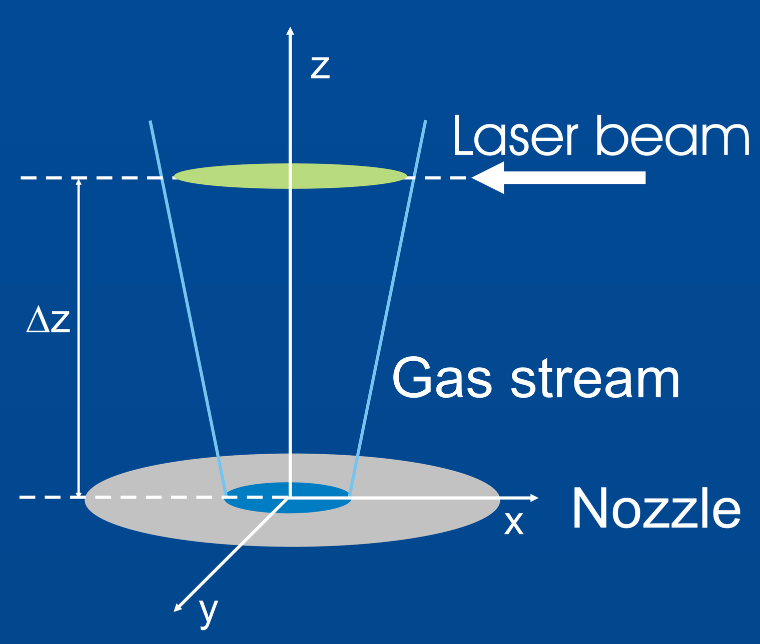

Fig. 1: Nozzle aperture schematics

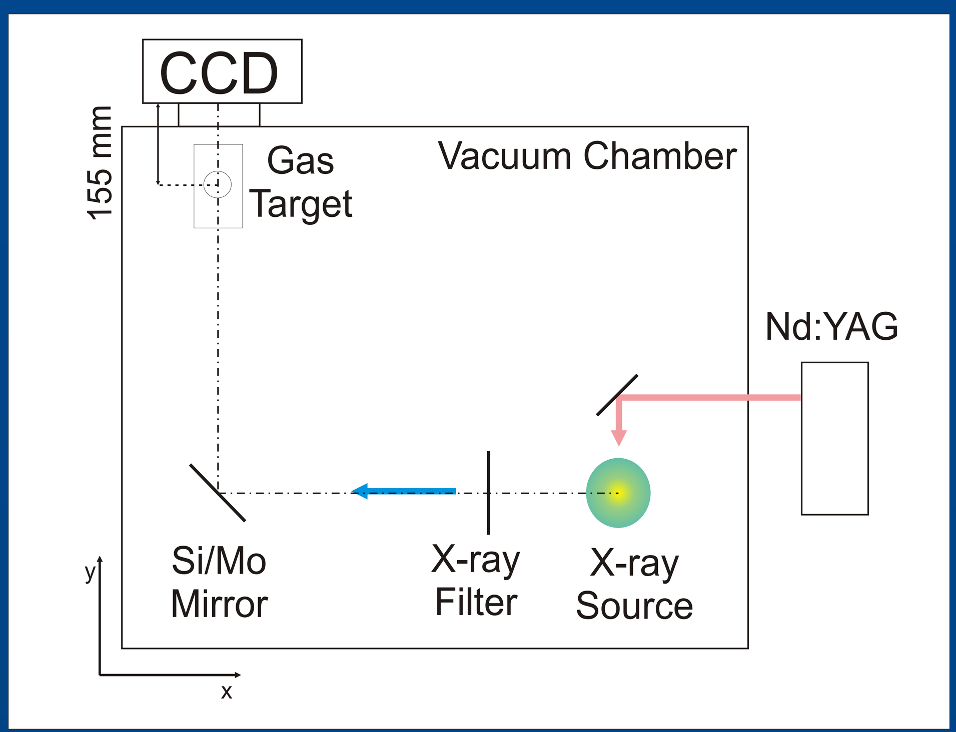

Fig. 2: Experimental arrangement.

We assume Gaussian gas density profile and the transmission function is:

$$T_G(x,\Delta z) = e^{-\mu \int_{-\infty}^{\infty} \rho_0(\Delta z)\, e^{-\frac{(x^2+y^2)}{\sigma^2}}\, dy}$$

For computer modeling we need to know nitrogen mass density for selected nozzle. At fig. 3 is shown the shadowgraph for single stream nozzle and ln(T) at the distance Δz = 0.5 mm. The mass density is $3.7{\cdot}10^{-4}$ g/cm^3.

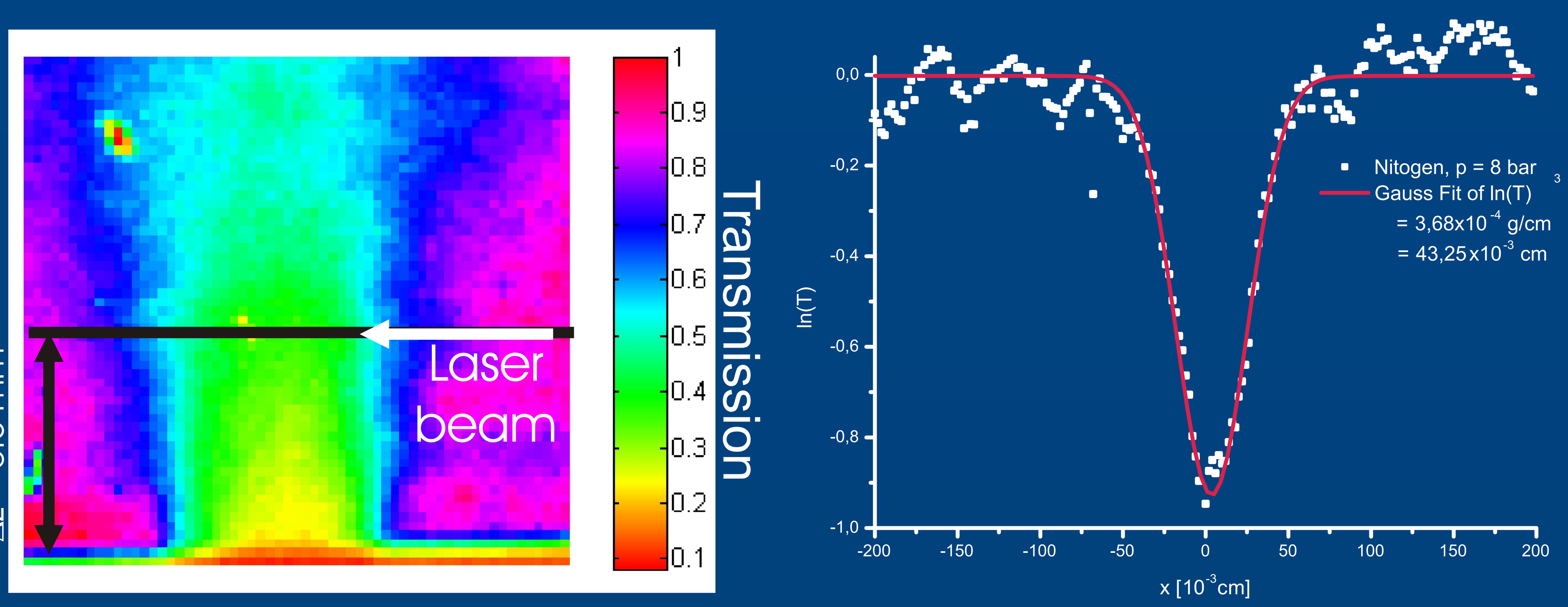

Fig. 3: Left - Shadowgraph for nozzle nr. 1. - Right - Logarithm of transmission for nitrogen at the distance Δz = 0.5mm, p = 8 bar, Δt = 900 μs.

Modeling space-time characteristics of laser plasma

Time development of time distribution of laser plasma generated by Nd:YAG laser in nitrogen gas was modeled using Z* code [2]. The resulting distribution of plasma density $\rho_0(\Delta z$ = 0.5 mm) was used. Spatial density distributions of plasma density and electron temperature at time t = 10 ns (corresponding to the laser peak power) is seen from Fig. 4. At this time the laser beam passed through gas jet, creating the plasma of temperature T_e ~ 40 eV and shock wave propagates into the gas target.

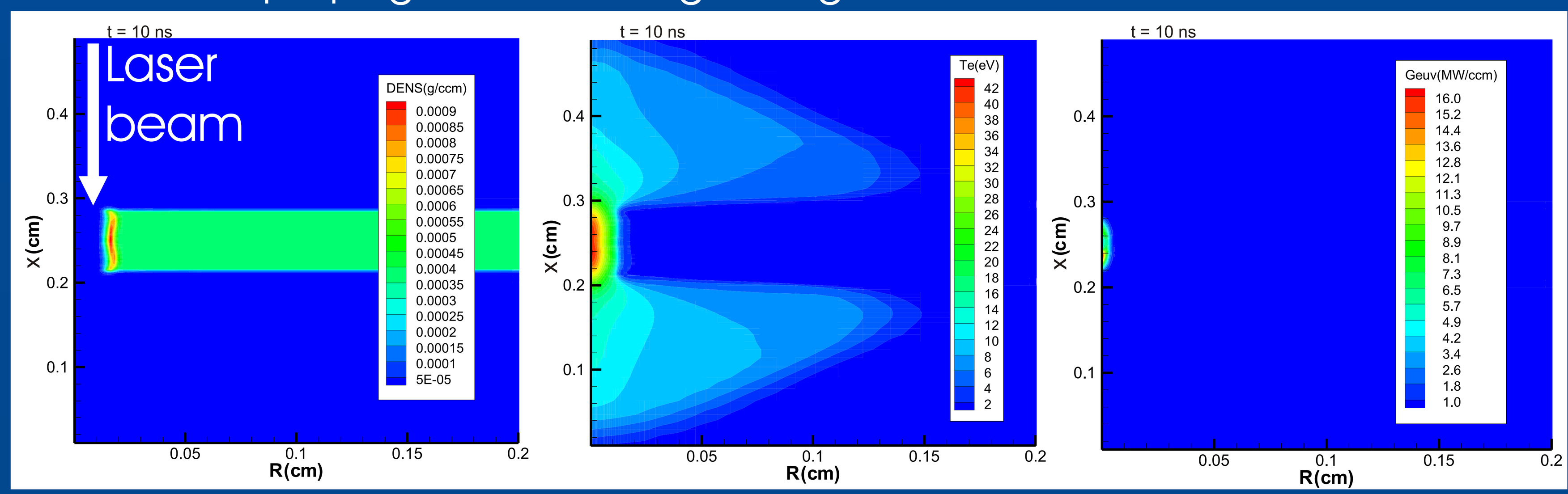

Fig. 4: Plasma mass density end plasma electron temperature Te, distribution of emmited instantaneous power Q_{euv} from unit volume of plasma in the wave length range 2.8766 - 2.8867 nm at time t = 10 ns.

The instantaneous emitted power in the selected water window range has a barrel character of ~ 100 μm diam. and ~ 600 μm length at time of laser peak power.

Imaging of laser plasma

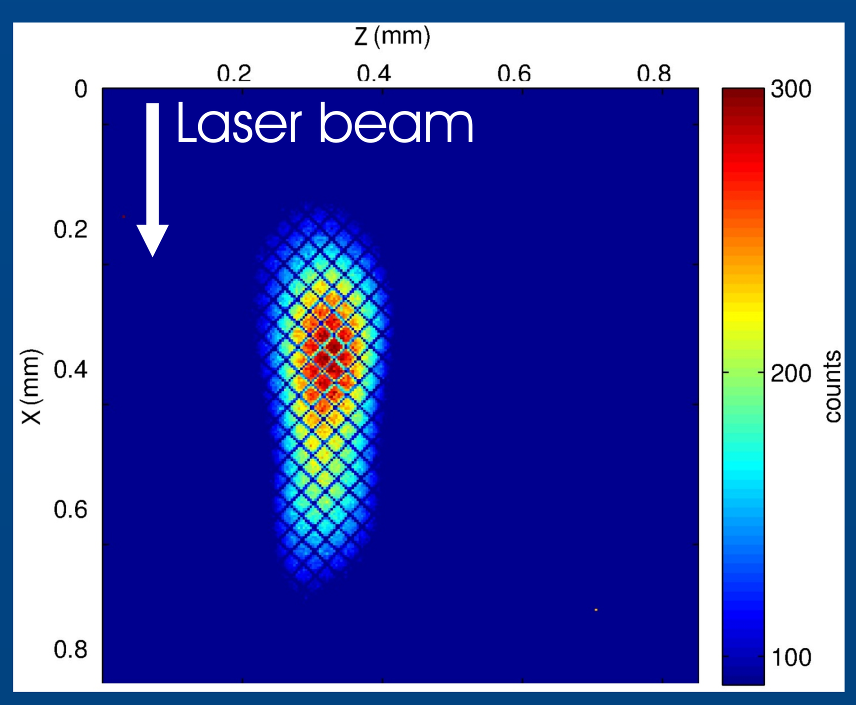

Fig. 5: Pinhole image of XUV emission from laser-produced nitrogen plasma

Nitrogen plasma was imaged by a pinhole camera using the hybrid semiconductor pixel detector Timepix operated in the /Time-over-Threshold/ mode. The magnification of the camera was 16x while the source - detector distance was 344 mm. The pinhole diameter was 50 um. A titanium foil filter of 0.4 um thickness was used to obtain quasi-monochromatic radiation at ~2.88 nm. The image is an average of 100 consecutive single-shot images recorded at 1 Hz repetition rate. Due to the high sensitivity and read-out speed of the Timepix device, single-shot acquisition of many consecutive images with repetition rate up to 3500 fps is possible. Thus, not only high quality imaging of the plasma radiation distribution is possible but also the pulse-to-pulse stability of the generated plasma can be easily assessed.

Conclusion

Mass density distributions for several gass-puff targets were measured by EUV radiography. The results for single stream nozzle and nitrogen were used for modeling of laser interaction with gas puff target. The results of modeling correspond properly with the experiment done in FBME laboratory. Further modeling and experiments with other gases are planned.

References

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